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CRYSTALLIZATION OF PYROXENES FROM BASALTS

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I. INTRODUCTION

Microscope studies of basalts from South Africa and the Pacific convince me that the pyroxenes of these rocks exhibit a gradual change in composition as crystallization proceeds.

The establishment of the course of crystallization of the natural pyroxenes is very important.

No one will deny the great significance of the reaction series of the plagioclases, and although the reaction series of the pyroxenes is fully as important, little more is known of it than the fact that a general enrichment in iron takes place as stated by Vogt, Fenner, and others.

The difficulty of establishing the course of these reaction series lies in the fact that very many mineral molecules enter into the natural pyroxenes. Many more data are required before it will be possible to determine the relations of different pyroxenes to different magmas;[1] but confining ourselves to basaltic magmas it is already possible to offer for consideration a general course of crystallization as far as the major constituents of the basaltic pyroxenes are concerned.

We know that the common pyroxenes of basalts are composed largely of metasilicates of magnesium, calcium, and iron. Neglecting for the present the minor constituents (the most important of which are sesquioxides and alkalies), the purpose of this paper will be to indicate the variations that take place between the three major silicates as pyroxenes crystallize from a basaltic magma.

To this end the minor oxides[2] in the pyroxene analyses have been neglected, the sum recalculated to 100 per cent and presented in terms of $FeSiO_3+MgSiO_3+CaSiO_3$.[3] It should be mentioned here that an enrichment of residual pyroxene in, say, iron does not mean enrichment of residual material as a whole in iron; cf. my studies on Pacific lavas (see footnote No. 10).

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[1] Valuable data bearing on the formation of ferriferous pyroxenes are given in a recent synthetic study by Bowen, Schairer, and Willems: *Am. Jour. Sci.*, **20**, 405, 1930.

[2] Titanium dioxide is, however, reckoned with silica.

II. ABUNDANCE OF PIGEONITE

The first conclusion reached from the following brief survey of basaltic pyroxenes will be surprising to some petrographers. It will be shown that the pigeonite (*i.e.* pyroxene rich in clinoenstatite and/or clinohypersthene) is a very common mineral; indeed, after certain varieties of feldspar it seems to be the most abundant mineral of eruptive rocks.

Wahl[4] pointed out the general occurrence of pigeonite in basaltic rocks twenty-five years ago, and Fermor[5] concluded six years ago that pigeonite was the most abundant pyroxene in nature. But this fact has not yet received proper attention, especially in the English literature. This mineral affords a striking illustration of our lack of knowledge regarding the actual nature of the mineral phases in rocks.

When Winchell[6] in 1900 examined pigeonite in the olivine diabase of Pigeon Point, Minnesota, he felt puzzled about the optical properties of this mineral, and concluded eventually that: "The abnormal optical properties . . . can scarcely be attributed to the chemical composition." That much was known then about the most abundant mafic mineral in nature. And even today very little attention is given to this mineral species. In standard textbooks on petrography and mineralogy little or nothing is said about it. Even the nomenclature is not established.

In 1900 Winchell[6] called the mineral pigeonite.

In 1905 Rosenbusch proposed the name magnesiumdiopsid.[7]

In 1906 Wahl[4], in his elaborate study, suggested the names: enstatitaugit, bronzitaugit, hypersthenaugit, enstatdiopsid, etc.

In 1906 Lacroix[8] designated it clinoenstatite or clinohypersthene; but later[9] he adopted Winchell's pigeonite.

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[3] Also expressed as Hy, En, Wo, respectively.

[4] W. Wahl, Die Enstatitaugite, Helsingfors, 1906, *Tsch. Min. Petr. Mitt.*, **26**, 1907, p. 1.

[5] L. L. Fermor, *Rec. Geol. Surv. India*, **58**, Part 3, 1925, p. 323.

[6] A. N. Winchell, *Am. Geol.*, **26**, 1900, p. 203.

[7] H. Rosenbusch, *Mikr. Phys.* **I**, 2, p. 206. This is the *salite* of Merian and Hoven, *Neues Jahrb. f. Min., B. Bd. 3*, 252, **1884**; *Tschermak's Mitt.* **13**, 213, 1893.

[8] A. Lacroix, *Bull. Soc. Sci. Nat. Ouest.*, **6**, 1906, p. 81.

[9] A. Lacroix, Minéral France, IV, **1910**, p. 767.

It seems to me that a mineral, or rather a mineral series, of such eminent importance should have a short, concise name, and I am therefore in agreement with Winchell and Lacroix in selecting the name pigeonite for all pyroxenes of small axial angle.

III. PYROXENES OF THE PACIFIC[10]

Within the vast Intra-Pacific petrographic province, basaltic rocks abound, and basaltic pyroxenes are encountered both as phenocrysts and as products of later crystallizations.

Chemical analyses of two Pacific pyroxenes are on record.

(1) *Early-formed crystals* of an olivine basalt from Haleakala, Maui, have been studied by Washington and Merwin.[11]

(2) *Pyroxenes of later crystallizations* from a basalt of Hiva Oa, Marquesas, have been analyzed by me.[12]

The results of the chemical analyses, recalculated in the manner described above, are:

TABLE I

	1	2
Hy	8	21
En	42	50
Wo	49	29

Taking these two analyses as representative of the composition of early- and later-formed pyroxenes, respectively, the course of crystallization must proceed along the line 1–2 of Fig. 1.

Microscope studies of more than 100 thin sections of Pacific rocks show that the axial angles of the pyroxene phenocrysts are 50°–60°, whereas the pyroxenes of the groundmass exhibit smaller axial angles varying from 0° to 50°. It is thus obvious that the general trend of the crystallization within the whole eruptive province runs from early-formed diopsidic augites to pyroxenes rich in clinoenstatite and/or clinohypersthene of later crystallizations.[13]

In most Pacific rocks two or more generations of pyroxenes are encountered; in some of the rocks they form a continuous series of mix-crystals, but in others there is no such transition, the phenocrysts being distinctly different from the pyroxenes in the groundmass. A few examples follow.

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[10] References to my previous paper, "Mineralogical Petrography of Pacific Lavas," *Am. Jour. Sci.*, **21**, 377–405, 1931, etc. will be made as "Pacific Lavas" or only "P.L." Washington's papers, "Petrology of the Hawaiian Islands" I to VI, *Am. Jour. Sci.*, **5**, 465; **6**, 100, 338, 409, 1923; **12**, 336, 1926; **15**, 199, 1928, will be referred to as (I), (II), (III), (IV), (V), (VI).

[11] H. S. Washington and H. E. Merwin, *Am. Jour. Sci.*, **3**, 1922, p. 117.

[12] T. F. W. Barth, *Neues Jahrb. f. Min.*, 1931.

[13] Such pyroxenes will be called pigeonites.

(3) *Olivine basalt*, south of Kaala, Kohala, Hawaii. Pyroxene phenocrysts (4.7 per cent of the rock) are commonly zoned, (+)2V around 58°; the refractive index β is about 1.69. The groundmass pyroxene makes up 40 per cent of the rock; the axial angle varies from 40° to 50°.

(4) *Olivine basalt*, Nihoa, Leeward Islands. Pyroxene phenocrysts (4.5 per cent of the rock) show the following properties: $(+)2V=58°\pm 2°$. $\alpha=1.680$, $\beta=1.687$, $\gamma=1.712$; all ± 0.003. $Z{:}c=44°$. The axial angle of the groundmass pyroxene is small, 20°–40°, but the indices of refraction are essentially the same as for the phenocrysts.

(5) *Basalt*. Kawaihae Gulch, Kohala, Hawaii. Pyroxene microphenocrysts, constitute 3 per cent of the rock and show the following properties: $(+)2V=58°$, α varies from 1.685 to 1.695, $\beta=1.690$ -1.700, $\gamma=1.720$–1.730. The groundmass pyroxenes make up 39 per cent of the rock; axial angle $=30°$–$40°$; $\beta=1.69$–1.70.

These three rocks have been analyzed by Washington,[14] and the mode or actual mineral composition has been determined by me.[15]

In this way it is possible to calculate with a fair degree of accuracy the average composition of the pyroxenes present,[16] and knowing also the proportion of phenocrysts to groundmass, and also the optical properties of the pyroxenes of both generations, one can offer a good estimate of the composition of each of them, thus:

TABLE II

	3		4		5	
	Phenocr.	Gr. mass	Phenocr.	Gr. mass	Phenocr.	Gr. mass
Hy	8	27	6	14	8	24
En	45	52	44	66	44	49
Wo	47	21	50	20	48	26

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[14] Nos. 3 and 5 in (I), p. 487, columns 2 and 1, respectively. No. 2 in (V), p. 344, column 3.

[15] Nos. 3, 4, and 5 are Nos. 14, 13 and 44, respectively, of my paper, "Pacific Lavas." The underlying data for the calculation of the composition of these three and the following pyroxenes are also to be found in that paper.

[16] Pyroxene constitutes between 40 and 50 per cent of these rocks, it is the only essential ferromagnesian mineral, consequently the inferred composition may be taken as essentially correct.

In the Pacific one also finds rocks carrying only one generation of pyroxenes. Some of these rocks have been analyzed and the modes have been established, and finally, the composition of the pyroxenes has been calculated.

The following rocks carry pyroxene mostly as phenocrysts:

(6) and (7). *Basanite*, Haleakala, Maui, Nos. 37 and 31 in "P.L." Analyses in (VI), p. 211, Cols. 5 and 7.

(8) *Picrite basalt*, Kaula Gulch, above Ookala, Mauna Kea, No. 28 of "P.L." Anal. in (I), p.500, Col. 3.

(9) *Limburgite basalt*, Pimoa Cone, Maui, No. 28 of "P.L." Anal. in (VI), p. 214, Col. 2.

(10) *Olivine basalt*, Nonopapa, Niihau, No. 12 of "P.L." Anal. in (V), p. 332, Col. 4.

The compositions of the pyroxenes of these rocks are:

TABLE III

	6	7	8	9	10
Hy	13	15	17	22	25
En	38	35	36	28	22
Wo	49	50	46	50	53

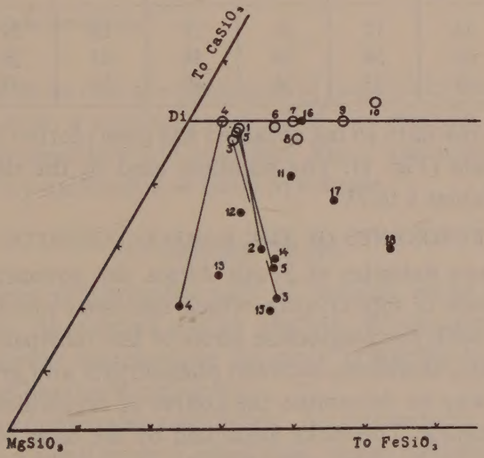

FIG. 1. Pyroxenes from the Pacific.
○ Phenocrysts
● Groundmass pyroxene
For explanation see text.

In the following rocks the pyroxene occurs in the groundmass.

(11) *Olivine basalt*, W. end of Taiohae, Nukuhiva, Marquesas, No. 3 in "P.L." Analyses in Washington, Barth, and Keyes, Petrology of the Marquesas Islands. (To be published).

(12) *Labradorite basalt*, flow of 1887, Mauna Loa, No. 47 of "P.L." Anal. in (II), p. 113, Col. 4.

(13) *Picrite basalt*, Nihoa, No. 27 of "P.L." Anal. in (V), p. 344, Col. 4.

(14) *Basalt* from crater wall, Kilauea, No. 45 in "P.L." Anal. in (III), p. 342, Col. 2.

(15) *Olivine basalt*, W. of Kawakaia, Kilauea, No. 15 of "P.L." Anal. in (III), p. 346, Col. 2.

(16) *Chrysophyric basalt*, Kaula Gulch, above Ookala, Mauna Kea, No. 34 of "P.L." Anal. in (I), p. 500, Col. 1.

(17) *Gabbro* included in basalt, summit of Hualalai. Anal. in (II), p. 104, Col. 3.

(18) *Labradorite basalt*, Nihoa, No. 53 of "P.L." Anal. in (V), p. 344, Col. 2.

The compositions of the pyroxenes in these rocks are:

TABLE IV

	11	12	13	14	15	16	17	18
Hy	19	15	17	24	27	16	27	39
En	40	50	58	50	54	33	36	32
Wo	41	35	25	26	19	50	37	29

A review of the data so far obtained has been plotted in the composition diagram (Fig. 1). The numbers used in the diagram are those in the Tables I to IV.

IV. PYROXENES OF THE KARROO DOLERITES

In the Karroo dolerites of South Africa the pyroxenes form a continuous series of mix-crystals which has been precipitated simultaneously with the plagioclase series of the feldspars. One can not discriminate, therefore, between phenocrysts and groundmass, and the only way to determine the course of crystallization is by studying the zoning. The rocks examined by me have been chemically analyzed by Radley, and thus the average composition of the pyroxenes can be calculated.[17]

[17] The underlying data for these calculations are given in a joint paper by Daly and the author. Dolerites associated with the Karroo System, etc. *Geol. Mag.*, **67**, 1930, p. 97.

TABLE V

	1*	2	3	4
Hy	32	34	27	25
En	40	43	52	41
Wo	28	23	21	34

* The numbers in this table correspond to the rocks 3188, 3246, 3294 and 3372, respectively, in the paper cited.

In these rocks the pyroxenes are conspicuously zoned, so it is difficult to obtain exact optical data. The mean index of refraction is always around 1.68, but a definite relationship to the size of the optic angle could not be established. Invariably the core has a larger axial angle than the surrounding shell, for example:

		2V*	Z:*c*
Crystal from rock No. 2	Core	40°	23°
	Border	0°	29°
Crystal from rock No. 1	Core	49°	35°
	Medium layer	45°	35°
	Border	0°	31°

* Extreme values are given.

It is thus obvious that the pyroxenes of these rocks are not homogeneous, but form a continuous series of mix-crystals, from diopside-rich to hypersthene-rich members. Fig. 2 presents graphically the course of crystallization of these pyroxenes.

V. DECCAN TRAPS

Another large petrographic unit of basaltic rocks is found in Deccan, India. As pointed out by Merwin, Washington, and Fermor, the pyroxene representing the main crystallization (groundmass) of these basalts is pigeonite.

My studies confirm this completely. All pyroxene in the groundmass exhibits a small to very small axial angle: frequently uniaxial crystals are met with, and in some cases the axial angle opens up again in a plane normal to the plane of symmetry. For example: Pyroxene from basalt of Katem quarries, Rajamundri, Madras.

Core	Border
Y = *b*-axis Z:*c* = 30° 2V = 5°–0°	X = *b*-axis Z:*c* = 30° 2V = 20°

This indicates a pigeonite very low in lime; indeed, only three other occurrences of a monoclinic pyroxene of such an extreme composition are on record.[18]

The pyroxenes of these traps are very heterogeneous, values of the optic angle ranging from 0° to 40° are frequently found in the same thin section, even within the same mineral grain; but no regular zoning was observed. Several measurements indicate that the core is generally more calcic than the border, but no definite data can be given.

A study of the phenocrysts, however, is very instructive. Phenocrysts, or rather microphenocrysts, are very rare; indeed, in the strict sense of the word no phenocrysts at all occur; but here and there one can see relatively large crystals of pyroxene, often associated with feldspar laths, attaining a length of about one millimeter, as obvious products of an earlier crystallization of the basaltic magma.

In such crystals the axial angle is always around 60°. For example, the rock from the Katem quarries carries a few larger pyroxene grains showing $(+)2V = 57° \pm 2°$. Phenocrysts in a trap from Hingancy, Hyderabad, exhibit axial angles of from 50° to 60°, the mean index of refraction being around 1.70, (lowest observed index $= 1.69$, highest 1.73). The axial angle of the groundmass pyroxene of the same rock averages about 20°. Similar values are given by Fermor[4] for pyroxene from the Bhusawal lavas ($2V = 20°$), and by Merwin[19] on (groundmass) pyroxenes from traps of Chhindwara, Seoni, and Neemuch: axial angles range from very small up to 30° in the plane of symmetry, $\alpha = 1.700–1.710$, $\gamma = 1.725–1.735$.

From these data it becomes apparent that the earlier formed crystals are diopsidic, whereas those formed later are hypersthenic in composition.

More accurate data can be obtained from a chemical analysis made on a pyroxene from the groundmass taken from a trap at Kolhapur.[20]

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[18] W. Wahl, (lit. 3.); A. Osann, *Centrblatt f. Min.*, **1907**, p. 705; P. Quensel, *Bull. Geol. Inst. Uppsala*, **11**, 76, 1911.

[19] *Bull. Geol. Soc. Am.*, **33**, 1922, p. 769.

The analysis presented in terms of the usual silicate molecules may be compared with the phenocrysts of the aforementioned trap of Hingancy. The compositions are as follows:

TABLE VI

	5	6
	Phenocryst,* Hingancy	Groundmass Pyroxene, Kolhapur
Hy	18	38
En	32	37
Wo	50	25

* Approximate composition as estimated from the optical properties.

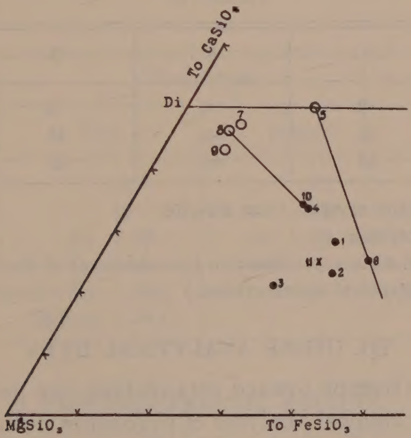

FIG. 2. 1, 2, 3, 4. Pyroxenes from Karroo the dolerites.
5, 6, 11. Pyroxenes from the Deccan traps.
7, 8, 9, 10. Pyroxenes from the Cape Verde Islands.
○ Phenocrysts
● Groundmass pyroxene
For explanation see text.

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[20] Separation made by Merwin, analysis by Washington: analysis cited by Fenner, *Am. Jour. Sci.*, **18**, 1929, p. 235.

As all the phenocrysts in the Deccan traps are very similar to this one (No. 5), while the groundmass pyroxenes generally approximate the above-stated composition (No. 6),[21] these two types of pyroxenes may be taken as representing early-formed pyroxene and pyroxene of the groundmass of the basaltic magma. The course of crystallization of the pyroxenes is thus indicated by the line 5–6 in Fig. 2.

VI. CAPE VERDE ISLANDS

C. Doelter[22] some fifty years ago made a comprehensive study of the pyroxenes of the rocks of the Cape Verde Islands. His method of investigation is more adequate than that of most petrologists, who usually confine themselves to the study of the phenocrysts, not taking the trouble to attack the more difficult task of examining the groundmass.

The following series of analyses (recalculated) indicates the course of crystallization of the pyroxenes in the basalts of these islands.

TABLE VII

	7	8	9	10
Hy	9	8	9	24
En	44	46	48	41
Wo	47	45	43	34

7. Very large augite crystals from dolerite.
8 and 9. Loose crystals.
10. Augite of the main crystallization (groundmass) of the olivine basalt.
(See Fig. 2 for a graphical representation.)

VII. OTHER ANALYTICAL DATA

As a further attempt toward establishing the general course of crystallization, chemical analyses of pyroxenes from different parts of the world have been collected and recalculated in the way described.

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[21] It is worth noting that the analysis of the groundmass pyroxene from Kolhapur corresponds very closely to the *normative* composition of the pyroxene as calculated from the rock analysis. The normative compositions of other trap pyroxenes as well as of pyroxenes from the Oregon plateau basalts, have also been calculated, using Washington's analyses (*Bull. Geol. Soc. Am.*, **33**, 1922, p. 765), and they all are similar in composition to this one. The average normative composition of the Deccan pyroxenes as calculated from 11 analyses is: Hy=31, En=44, Wo=25, and is presented by point 11 of Fig. 2.

[22] C. Doelter, *Vulkane der Capverden und ihre Producte*, Graz, 1882.

Loose crystals and also large phenocrysts in basalts have been repeatedly analyzed, but only a few chosen at random among the more recent analyses have been recalculated and plotted in the diagram (Fig. 3). From these observations it is clearly shown that the phenocrysts generally are diopsidic augites.

Reliable analyses of groundmass pyroxenes are rare, but all of them, so far as known, indicate pyroxenes low in lime (pigeonites).

These features are clearly brought out by the graphic representation of Fig. 3, which shows that, throughout the world, the general course of the crystallization of basaltic pyroxenes is similar to that which was found to exist in the Pacific, South Africa, India and the Cape Verde Islands. Regarding the noteworthy occurrence of a lime-poor pigeonite as phenocrysts in a lava of Mull (circle 16), see discussion under topic VIII.

It may be added that on a pyroxene in a basalt from St. Paul, Pribilof Islands, Bering Sea,[22a] the following measurements were made:

	Phenocrysts		Groundmass pyroxene
	Core	border	
$2V_\gamma$	56°	32°	small
$Z{:}c$	46°	44°	about 30°
β	*Ca.* 1.69	*Ca.* 1.69	*Ca.* 1.69
(Lowest observed index: 1.685, highest: 1.715.)		(Lowest index: 1.685, highest: 1.720.)	

VIII. BRITO-ARCTIC BASALTS

In the widespread basaltic rocks of the Brito-Arctic province pigeonites have long been known. In an andesite from Mull even *phenocrysts* of pigeonite are encountered[23] (plotted as No. 16, Fig. 3).

[22a] Cf. Washington and Keyes, *Am. Jour. Sci.*, **20**, 321, 1930.

[23] A. F. Hallimond, *Mineral. Mag.*, **17**, 1914, p. 97.
H. H. Thomas, E. G. Radley, Petrology of Mull, Loch Aline, etc. *Mem. Geol. Surv. Scotland*, **1924**.

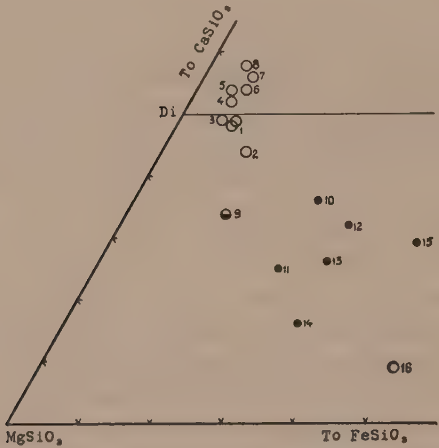

FIG. 3. ○ Phenocrysts ● Groundmass pyroxene

1. Pyroxenes from Vesuvius and Etna, Washington and Merwin, *Am. Jour. Sci.*, **50**, 20, 1921.

2. Pyroxene from Stromboli, Kôzu and Washington, *ibid.*, **45**, 463, 1918.

3. Pyroxene from Kilimanjaro, Washington and Merwin, *Am. Mineral.*, **7**, 123, 1922.

4, 5, 8. Pyroxenes from Sparbrod, Gehülfensberg, and Todtenköpfchen, Xenia Galkin, *Neues Jahrb. f. Min., B. Bd.*, **29**, 682, 1910.

6. Pyroxene from Laacher See, R. Brauns, *N. Jahrb. f. Min., B. Bd.*, **57**, 131, 1927.

7. Pyroxene from Alban Hills, Washington and Merwin, *Am. Mineral.*, **8**, 104, 1923.

9. Pyroxene from Uifak, Nicolau, *loc. cit.*, (26).

10, 11. Pyroxenes from Pigeon Point, Winchell, *loc. cit.*, (6).

12, 14. Pyroxenes from Onega and Åland, Wahl, *loc. cit.*, (4).

13, 15. Pyroxenes from Palisade Diabase, Lewis, *Am. Jour. Sci.*, **26**, 155, 1908.

16. Pyroxene from Mull. Hallimond, *loc. cit.*, (23).

In Icelandic basalts Hawkes[24] was the first to notice the presence of pigeonite, and later Holmes[25] described this mineral from different basalts of the Arctic region.

From the basalts of Uifak (Greenland) Nicolau[26] has described a lime-poor pyroxene which afterwards was re-examined by Wahl and identified as pigeonite (entered in Fig. 3 as No. 8).

From these descriptions it is difficult, however, to get an idea of the sequence of crystallization.

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[24] L. Hawkes, *Norsk. Geol. Tidsskr.*, **4**, 1916.

[25] A. Holmes, *Mineral Mag.*, **18**, 1918, p. 180.

[26] Th. Nicolau, *Meddelelser om Grönland*, **24**, 190. Copenhagen, 1900.

The following statements of Holmes seem to indicate a sequence opposite to that which has been found in other basaltic areas.

In Iceland olivine basalts from Onundafjord and Isafjord carry phenocrysts of pigeonite and in a basalt at Grundafjord a pigeonite "shades off on the borders and along terminations into augite. . . ."

But also the groundmass pyroxene is often said to be of the pigeonitic variety (Holmatindur, Eskifjord; Vágsfjord, Faeroes; etc.).

Also certain basalts from Spitzbergen, Franz Joseph Land, and Hooker Island carry, according to Holmes, pigeonite in the groundmass.

In the memoir of the rocks from the Mull district it is stated that "in some non-porphyritic olivine dolerites columnar augites have a core, now preferentially replaced by hornblende, which, no doubt, originally consisted of either enstatite augite, or rhombic pyroxene."[23] But it seems to me that there is little reason for this conclusion; the original core could have been made up of olivine as well.

In a recent paper dealing with rocks of the same region Walker[27] writes that the pyroxene is a monoclinic enstatite augite with 2V around 60°! Thus there seems to be some confusion in the nomenclature used by some British authors.

Be that as it may, phenocrysts of pigeonite seem to occur in different basalts of the Brito-Arctic province. Thin sections of these rocks unfortunately have not been available to me; I can only state that I have never seen true phenocrysts of pigeonite in any basalt from other parts of the world. One can sometimes observe larger crystals of pigeonite in basalts, but in such cases a closer examination always has shown that these crystals were originally olivine that has been changed over to a pyroxene in accordance with the well-known reaction principle of Bowen.[28] Actually such basalts contain considerable amounts of both olivine and quartz, and the pyroxene is consequently, so to speak, still *in statu nascendi*, the reaction between magma and olivine being arrested before it was completed. Such lavas have been described by me from the Pacific.

The actual occurrence of pigeonitic phenocrysts in Brito-Arctic lavas might likewise be accounted for in the same way.

In agreement with the experimental studies of Bowen[29] the present survey indicates a complete series of solid solutions in the natural basaltic pyroxenes and consequently fails to demonstrate the discontinuity area proposed by Asklund.[30] As shown by him, calculations of the normative composition of a great many pyroxenes indicate that iron-poor members of the diopside-clinoenstatite series should break down and form two different natural pyroxenes. According to his calculations the natural pyroxenes would have a rather complicated crystallization history. Under certain conditions enrichment even in lime might take place. These calculations suggest therefore an alternative explanation of the aforementioned occurrence of pigeonitic phenocrysts in Brito-Arctic basalts. More definite data of the mode of occurrence of the phenocrysts are, however, needed to settle this question.

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[27] Frederick Walker, *Mineral. Mag.*, **22,** 1930, p. 368.

[28] N. L. Bowen and O. Andersen, *Am. Jour. Sci.*, **37,** 487, 1914; O. Andersen, *ibid.*, **39,** 407, 1915.

[29] N. L. Bowen, *Am. Jour. Sci.*, **38,** 245, 1914.

Thanks are due to Dr. H. S. Washington for free use of his collections of rocks and thin sections, and to Dr. N. L. Bowen for criticism of the paper.

SUMMARY

Pigeonite is the most abundant pyroxene in volcanic rocks. Pyroxenes crystallizing from a basaltic magma exhibit a regular sequence of crystallization from diopsidic to hypersthenic, during which the content of $MgSiO_3$ may remain constant or increase slightly.

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[30] B. Asklund, Petrology of the Stavsjö Area etc., *Sveriges Geol. Undersökning*, Ser. *C*, Årsbok *17*, No. 6, Stockholm, 1925.

MINERAGRAPHIC IDENTIFICATION OF PSILOMELANE AND MANGANITE[1]

S. R. B. Cooke,[2] Warren Howes[3] and Alden H. Emery[4]

In the course of some recent mineragraphic work on the manganiferous iron ores of the Cuyuna Range, Minnesota, undertaken by the Mississippi Valley Experiment Station of the United States Bureau of Mines in cooperation with the Missouri School of Mines and Metallurgy, Rolla, Missouri, it was necessary to make quick identification of the various oxides of iron and manganese. Hematite and psilomelane were found to be the predominating minerals, although the occurrence of manganite and pyrolusite was important to the problem in hand. The mineragraphic characteristics of these four minerals are shown in Table 1.

Pyrolusite can be readily distinguished from the other minerals on the basis of its luster, color, surface characteristics and hardness. The pitted surface of the hematite and its creamy white color usually serve to make its identification positive. Psilomelane and manganite jointly can be distinguished from the hematite and pyrolusite, but difficulty was encountered in this investigation in visually distinguishing between the two. Psilomelane pseudomorphs after manganite were often confusing. Although the hardness and reactions with HNO_3 and HCl are apparently diagnostic, the results in practice were not distinctive enough to permit certain identification at all times. The action of other etchants was therefore studied. The results are shown in Table 2.

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[1] This paper has resulted from cooperative work between the U. S. Bureau of Mines and the Missouri School of Mines and Metallurgy, Rolla, Missouri. Published by permission of the Director, U. S. Bureau of Mines. (Not subject to copyright).

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[4] Geologist and Assistant to Chief Engineer, Experiment Stations Division, U. S. Bureau of Mines, Washington, D.C.

TABLE I

MINERAGRAPHIC CHARACTERISTICS OF SEVERAL MINERALS

Characteristics		*Hematite*	*Psilomelane*	*Manganite*	*Pyrolusite*
Luster		Bright	Bright, but less than hematite	Bright, between hematite and psilomelane	Bright when well polished
Color		Creamy white	Gray	Gray	Brown when not well polished; gray with good polish
Surface		Much relief, considerable pitting	Smooth	Smooth	Rough; some specimens very difficult to polish
Hardness		5.5 to 6.5, brittle	5 to 6, brittle	4	2 to 2.5
Structure		Pitted, irregular grains	Varied	Radiating needles	Varied, some times banded
Etch Behavior	HNO_3	Negative	Tarnishes; rubs nearly clean	Negative	Negative
	HCl	Negative	Tarnishes; rubs faint brown	Negative	Tarnishes; rubs pale
	KCN	Negative	Negative	Negative	20 per cent solution — negative; dilute — rapid tarnish
	$FeCl_3$	Negative	Negative	Negative	Tarnishes dark brown; rubs pale

TABLE II

ETCHING OF HEMATITE, PSILOMELANE, MANGANITE AND PYROLSUITE

Reagent	*Effect of Reagent on*			
	Hematite	*Psilomelane*	*Manganite*	*Pyrolusite*
H_2SO_3(6–8 per cent SO_2)	Negative	Darkens, with sorbitic pattern	Darkens very slightly with long contact	Darkens rapidly; deeply etched
Equal volumes of HNO_3, H_2O_2, H_2O used cold	do	Similar to above but much more rapid	do	do
$FeSO_4 \cdot (NH_4)_2SO_4$ (0.3N) 10 per cent H_2SO_4 used hot	do	Darkens rapidly	do	do
HF	do	do	Accentuates cleavage cracks	do

Because of its moderate rate of attack and characteristic etch pattern on psilomelane, sulphurous acid is recommended as a distinguishing etching reagent to those desiring to differentiate rapidly between the manganese minerals.

Figs. 1 and 2 are photographs of the same field in a polished section of a briquet containing hematite, psilomelane, manganite, and pyrolusite. The specimen in Fig. 1 was unetched, but in Fig. 2 it was etched for 90 seconds in a solution of 8 per cent sulphurous acid.

Comparison between the two figures shows that the hematite and manganite are unattacked, the psilomelane is darkened with a spotted or sorbitic pattern, and the pyrolusite is blackened. The etch readily brings out the mineral components of the mixed grains. The true nature of the grain of psilomelane pseudomorphic after manganite [Ps(a)] is also shown.

Sulphurous acid is a very convenient etching reagent for differentiating between manganese minerals, especially in ores where pseudomorphism is encountered.

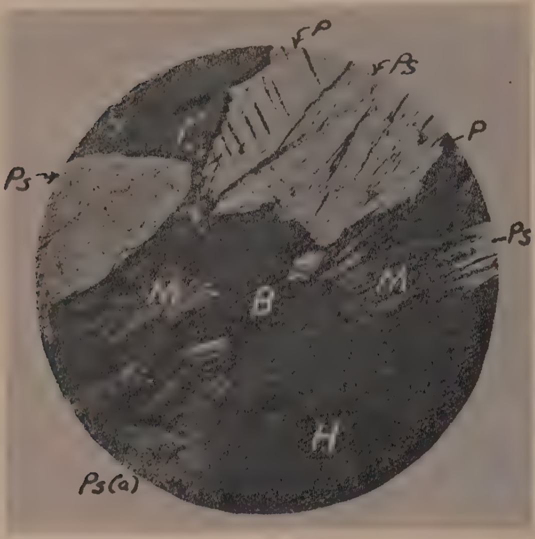

FIG. 1. Unetched. Magnification 50 x.

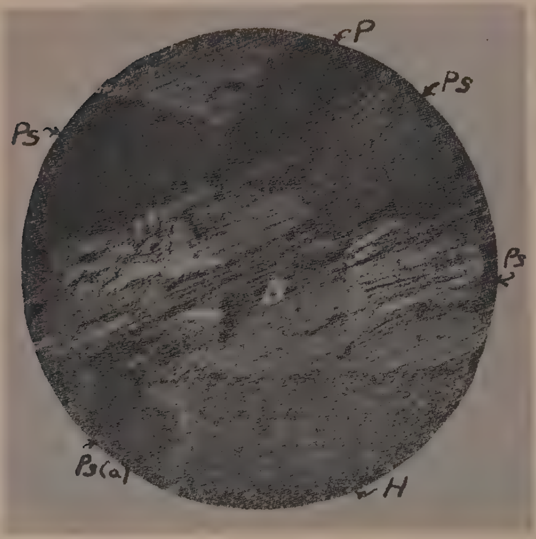

FIG. 2. Etched for 90 seconds in H_2SO_3.
Magnification 50 x.
Legend: B = bakelite matrix; P = pyrolusite;
Ps = psilomelane; M = manganite; H = hematite;
Ps(a) = psilomelane pseudomorphic after manganite.

CLARKEITE; A NEW URANIUM MINERAL

Clarence S. Ross, E. P. Henderson and E. Posnjak*

Occurrence and Association

The pegmatites in the vicinity of Spruce Pine, North Carolina, have probably yielded more uraninite, and related uranium minerals than any other locality in the eastern United States. During mining operations for mica and feldspar, uraninite, gummite, uranophane and antunite have been found. These minerals seem to occur with mica in albitized areas of the pegmatite, and associated with the variety of zircon known as cyrtolite, and with monazite.

Many specimens of uranium ores from Spruce Pine have been observed to contain a dark brown to brownish black material which seemed to have definite optical properties that distinguished it from the associated gummite. Most of this material was intimately intergrown with gummite, or uranophane, but one specimen in a lot secured from Spruce Pine several years ago, and one from the Roebling collection of the National Museum were so pure that very careful hand picking yielded material suitable for analysis. This material has been found to be a new mineral with distinct, chemical, optical and X-ray properties, which it is proposed to call *clarkeite* after Professor Frank Wigglesworth Clarke.

The uranium minerals of Spruce Pine make strikingly beautiful specimens. In some there is a central core of black, sub-metallic uraninite. This is surrounded by a zone of dark reddish brown clarkeite; this by brilliant orange-red gummite; and the whole by an outer zone of bright yellow uranophane. The various zones vary in width but in the larger specimens they may be several centimeters wide.

Physical and Chemical Properties (E.P.H.)

Clarkeite is massive, without cleavage, has a conchoidal fracture and a hardness of 4 to 4.5. The specific gravity is 6.39. The color is very dark brown in the hand specimen and reddish brown to orange brown in microscopic grains. The luster is slightly waxy and the streak is lighter in color than the mineral and more of a yellowish brown. The following analyses were made on selected material from two specimens:

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TABLE I

ANALYSES OF CLARKEITE, E. P. Henderson, Analyst

	Analysis No. 1			*Analysis No. 2*[a]		
MgO	0.28	.0069	.1341			
CaO	2.84	.0506		1.10	.0196	.0932
PbO	3.71	.0106		3.70	.0162	
K_2O	0.48	.0051		1.42	.0151	
Na_2O	3.44	.0555		2.61	.0421	
BaO	None			0.04	.0002	
UO_3	81.72	.2857	.2857	82.76	.2894	.2894
Fe_2O_3	0.18			0.50		
Al_2O_3	0.92					
Rare Earths	2.62			1.12		
H_2O	3.36	.1865	.1865	5.22[b]	.2886	.2886
SiO_2	0.50	.0082		0.30		
Insol.	0.14			1.20		
Total	100.19			99.97		

[a] Duplicate analyses were made.

[b] H_2O at 110° was 0.64 and +110° was 4.58.

Analysis No. 1 was made upon the material found in the Roebling collection; analysis No. 2 was made upon the specimen that was first observed to be distinct from gummite.

The chemical formula calculated from analysis No. 2 is $RO \cdot 3UO_3 \cdot 3H_2O$. Alkalies are the essential RO constituents and sodium predominates over potassium. Analysis No. 1 is closely similar to No. 2, the only essential difference being a slight excess of calcium in the former. The quantity of lead and of alkalies is nearly the same in the two analyses, and the uranium contents agree very closely. Both analyses contain only small quantities of iron and aluminum oxides but there is a difference in the water content.

Under the microscope a greater proportion of opaque impurities (probably uraninite) were revealed in sample No. 1 than in No. 2, but the latter probably contained slightly more included gummite. A comparison of the analysis of uraninite and a so-called gummite from Spruce Pine, North Carolina, is shown in Table No. II. From these analyses it can be seen that a slight excess of uraninite or gummite, say less than 5 per cent, would not be noticeable in the analytical results.

TABLE II

ANALYSES OF URANINITES AND GUMMITES FROM NORTH CAROLINA

	Uraninite		*Gummite*
	X	XI	3
UO_3	50.83	44.11	77.99
UO_2	39.31	46.56	
ThO_2	2.78	3.04	1.06
CeO_2	0.26		
$(La, De)_2O_3$	0.50		
$(Y, Er)_2O_3$	0.20		
Fe_2O_3	trace		0.29
Al_2O_3	—	—	0.86
PbO	4.20	4.53	5.28
CaO	0.85	0.23	0.90
MgO	0.30	0.30	none
Na_2O			0.51
K_2O			0.86
H_2O	1.21	undet.	8.90
N	0.37	undet.	
SiO_2	0.08	0.13	1.97
BaO	—	—	2.16
Insol.	0.10	0.06	0.08
	100.99	98.91	100.86

Analyses X and XI of uraninites, Spruce Pine, by W. F. Hillebrand.[1]
Analysis 3 by E. P. Henderson.

Analyses No. 3, Table II, was made on a specimen from the Wiseman mica mine, Mitchell County, North Carolina, (Specimen U.S.N.M., No. 86120) that was typical of material commonly known as gummite. This appeared homogeneous to the unaided eye, but a microscopic examination showed that it was a fine-grained aggregate, the complete homogeneity of which was questionable. This analysis was made in order to compare a typical specimen of gummite with clarkeite and to test the character of the material used in the X-ray diffraction patterns. Hillebrand in discussing the North Carolina uraninites says:

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[1] Hillebrand, W. F., *Amer. Jour. Sci.*, (V) **40**, 384, 1890; also *U. S. Geol. Surv., Bull.* **78**, 1891.

The material was analyzed mainly to learn if rare earths enter into its composition. No. X represents the composition of the purest sample available and No. XI of the residue after extraction of the yellow oxidation products by very weak HCl. No really unaltered uraninite appears to have been found in North Carolina.

There is but little doubt that the opaque specks found in the clarkeite are uraninite for dilute mineral acids dissolve the clarkeite rather readily leaving behind minute dark specks which are decomposed on continued boiling. A visual estimation of the percentage quantity of the uraninite in the analyzed specimen of clarkeite would be somewhere in the neighborhood of 1 or 2 per cent.

Analytical Procedure. Although no new or unusual methods were used for this analysis it may be advisable to briefly outline the general analytical procedure.

Clarkeite dissolves readily in mineral acids, hydrochloric acid being used in the sample decomposed for analysis. The mineral can be dissolved in very dilute acid (1 part acid to 4 parts water), and a small residue of supposed uraninite remained insoluble although by continued boiling the dark spots were decomposed and a granular white sandy residue remained, after which this residue was filtered and the ignition weighed and reported as insoluble.

The solution or filtrate from insoluble portions was evaporated to dryness and SiO_2 determined in the usual manner. Sulfuric acid was added to the silica filtrate and the solution evaporated and fumed, the lead being thus precipitated as $PbSO_4$.

Any barium present would be precipitated and separated from the solution along with the lead as a sulfate. The lead sulfate was dissolved off the filter paper by a solution of ammonium acetate and next converted into lead chromate and weighed; the remaining residue left on the filter paper being insoluble in ammonium acetate was ignited and weighed as $BaSO_4$ and later qualitatively tested by a flame test.

The uranium was twice precipitated with ammonia and then on the third precipitation enough ammonium carbonate was added to the ammonia to dissolve the uranium. The insoluble material was filtered off and the rare earths present were removed before iron and aluminum were determined.

The uranium, after the ammonium carbonates had been completely decomposed was reprecipitated with ammonia, filtered and weighed as U_3O_8. This uranium precipitate was redissolved in nitric acid, evaporated to dryness and redissolved in water and the rare earths removed by adding oxalic acid.

Rare earths divide themselves into two groups, one being soluble in ammonium carbonate and hence must be recovered from the uranium oxide, while the other being insoluble remained with the iron and aluminum oxides.

In each case it was found that a larger portion of the rare earths were soluble in ammonium carbonate. The direct determinations are given in the following table.

Relative Distribution of Rare Earths between UO_3 and R_2O_3.

Rare earths recovered from	Analysis 1	Analysis 2
R_2O_3	0.48	0.34
UO_3	2.14	0.78

No attempt was made to separate these rare earths, so if thorium is present it is included as a rare earth. The other constituents were determined by well-known methods and need no comment.

The age of clarkeite was not calculated because there is evidence to show that the ratios between uranium and lead are considerably disturbed during the alteration of uraninites. H. V. Ellsworth[2] has recently shown how the lead uranium ratios on highly oxidized uranium minerals may give misleading or erroneous values.

Optical Properties (C.S.R.)

The following table gives the optical properties of Clarkeite and those of gummite for comparison:—

Table III

Optical Properties of Clarkeite and Gummite

	Color in thin section	Cleavage	Pleochroism	Indices of refraction			Birefringence	Dispersion	Axial angle	Optical character
				α	β	γ				
Clarkeite Spruce Pine No. 1	Orange	None	Slightly deeper orange	1.997	2.098	2.108	.211	$\rho<\nu$ weak	30° — 50°	(—)
Gummite Spruce Pine	Yellow	None	None	1.742	1.762	1.776	.034	$\rho<\nu$	60°	(—)

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[2] *American Mineralogist*, Vol. **15**, No. 10, p. 455.

It is probable that clarkeite has been previously assumed to be impure gummite but the data given in Table III show that the optical properties of gummite and clarkeite are distinct. The determination of the optical properties of gummite were made on a very small portion of beautiful material with orange red color, resinous luster, and conchoidal fracture that showed complete homogeneity. Unfortunately, however, the sample was too small for chemical or X-ray studies. Examination of less perfect material showed slight variations from the values given, but in no specimen did the optical properties approach those of clarkeite. It is to be noted that the optical data on gummite given here does not correspond with those recorded in the literature, and it is evident that gummite needs to be re-examined whenever adequate amounts of suitable material can be secured.

X-RAY PROPERTIES (E.P.)

X-ray powder photographs using K_α radiation of molybdenum were taken of the two samples of clarkeite and for comparison also of the supposed mineral gummite (U.S.N.M. No. 86120). In all the specimens examined, the analysis of which is shown in tables I and II considerable general blackening of the films took place and the

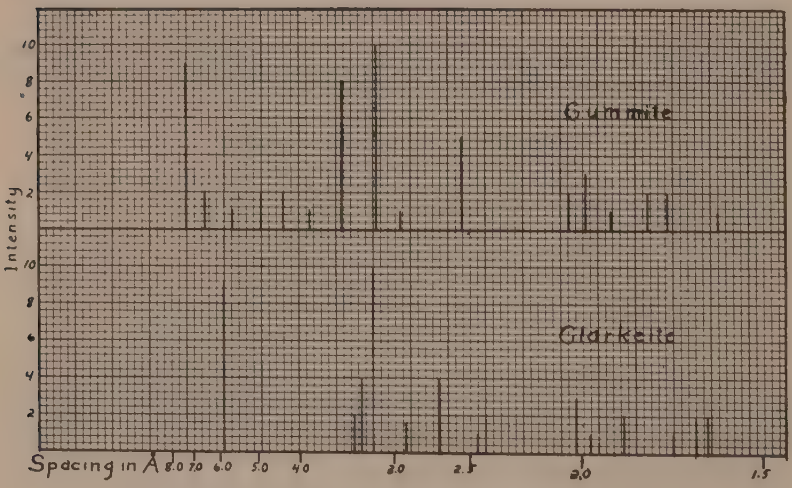

FIG. 1. X-Ray diffraction Pattern of Clarkeite and Gummite.

diffraction lines were broad, indicating the minuteness in size of the individual crystals. While possibly not all the material is crystalline, the reflections obtained showed clearly that the two samples of clarkeite were essentially identical and different from those obtained from the specimen of gummite. This is shown in Fig. 1 where the spacings and the estimated relative intensities of the lines observed on the films are given. While undoubtedly they do not represent the complete X-ray spectra of these substances and some of the lines may later be accounted for by some impurities present in these specimens, the powder photographs leave no doubt that the two uranium minerals represent different species.

GENETIC RELATIONS (C.S.R.)

Uraninite is the primary uranium mineral in the pegmatites at Spruce Pine, but its association with albitic areas and muscovite indicates that it was formed early in the post-pyrogenic stages of pegmatite formation. Clarkeite is a direct alteration product of uraninite since it surrounds uraninite and commonly contains residual grains of it. Gummite is later than clarkeite, since it surrounds and sends veinlets into the clarkeite. Uranophane surrounds gummite and veinlets of it cut the gummite and clarkeite.

The secondary minerals—clarkeite, gummite and uranophane—occur in fresh unweathered pegmatites and are clearly not the result of weathering processes, and it seems evident that their formation occurred during the late hydrothermal stages of pegmatite formation. Clarkeite seems to have formed from the action of hot sodic solutions on uraninite. It seems probable that the formation of clarkeite was related to the alteration of microcline to albite, an alteration that is marked in all pegmatites bearing rare minerals. At a later stage the solutions changed in composition until the clarkeite was unstable in their presence.

The compositions of clarkeite and gummite indicate that the solutions that caused the alteration of uraninite to clarkeite were alkali bearing. By the time gummite formed they had ceased to be alkalic but held notable amounts of silica so that the resulting mineral contained essential silica. At a later stage in the hydrothermal alteration process, the gummite and to a less extent clarkeite were altered to uranophane, with a higher calcium, silica and water content than either clarkeite or gummite.

SUMMARY

A mineral occurring at Spruce Pine, North Carolina, has distinctive chemical, optical and X-ray properties, and it is proposed to call this mineral clarkeite. The chemical formula is $RO \cdot 3UO_3 \cdot 3H_2O$ and the essential RO constituent is sodium.

Gummite, an associated mineral, has optical properties distinct from those of clarkeite, but differing from those given in the literature and so gummite should be re-investigated.

Clarkeite is a hydrothermal alteration product of uraninite, and gummite and uranophane are later products of the same process.

"ZEBRA" ROCK

David W. Trainer, Jr., *Cornell University*.

Introduction

Recently, the author was loaned for study purposes several specimens of the so-called "Zebra" rock, from near Argyle Station, East Kimberly, Western Australia, (Lat. 16° 15′, Long. 128° 40′), by Mr. George L. English, consulting mineralogist of Ward's Natural Science Establishment of Rochester, New York. A similar rock has been noted by T. Blatchford near Braeside Station on the Oakover River near the previously referred to locality, but it was not found in place.[1]

The "Zebra" rock from Argyle Station has been mentioned, its general microscopic characteristics and occurrence described by T. Blatchford.[2] The author is very fortunate in having had the use of an unpublished abstract of a paper dealing with this interesting formation which was read by Mr. R. A. Hobson before the Royal Society of Western Australia on July 8, 1930. This abstract gives the probable theories which may account for the peculiar banding in the rock and a diagrammatic cross-section showing the stratigraphic portion and general field relations of the formation.[3]

The purpose of this paper is to sketch briefly the facts known about the age and the occurrence of the "Zebra" rock, describe it from a macroscopic and microscopic standpoint and suggest some explanation which may account for its banded nature.

Occurrence and Characteristics

According to the diagrammatic cross-section by Mr. Hobson, the "Zebra" rock lies unconformably on the Pre-Cambrian of the region and directly below a limestone containing the small gastropod, Salterella hardmanni. Forms similar to this have been described by Hall and Wallcott and referred to the Lower Cambrian in North

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[1] Blatchford, T., Geological observations made whilst travelling in West Kimberly up the valley lying between the Penticost and King Rivers, then eastward across the Denham and Ord Rivers as far as Argyle Station on the Behn River. *Ann. Progress Rept. Geol. Surv. of Western Australia*, **1927**, p. 14, 1928.

[2] *Op. cit.*, p. 14, also Figure 9.

[3] Since this paper was completed, the author has received Mr. Hobson's complete paper, *Jour. Roy. Soc. W. Australia*, vol. **XVI**, 1930–31, pp. 57–70.

America. It would seem, therefore, from the conformable relation which exists between the bedded "Zebra" rock and the Lower Cambrian limestone above it, the unconformity between the base of the "Zebra" rock and the Pre-Cambrian, that the formation under discussion is probably of Lower Cambrian Age.[4]

A macroscopic examination of the specimen reveals that the rock is hard, very fine grained, has no apparent textural variations throughout its mass and breaks into smooth unevenly shaped fragments. The weathered surfaces have small cavities which are filled with a white material in the unweathered specimens. (See Fig. 1). The dark bands of the rock vary slightly in color in different specimens, from a light to a medium dark maroon (3K to 3M),

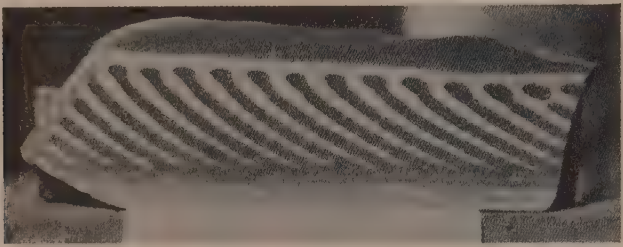

FIG. 1. Typical "Zebra" rock showing cavities on weathered surface.

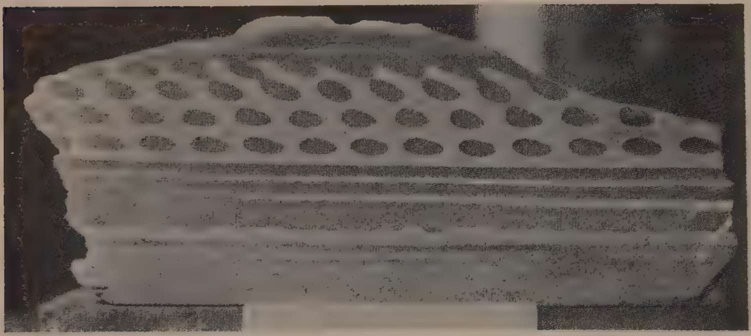

FIG. 2. Typical "Zebra" rock showing halos and dark bands.

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[4] Confirmed by Hobson.

while the light portions are very near a light grayish green (25 g 4).[5] Some of the specimens also show a leached or lighter colored portion or halo around the dark globular masses, this phenomena may be genetically connected with the banding and distribution of the color in the rock. (See Fig. 2).

Thin sections of the rock cut through adjoining light and dark areas, and a light area between two darker ones, show several very interesting facts. The extremely fine grained nature of the rock is confirmed, the constituent particles being so small that identification can not be made with any degree of certainty. Quartz and chlorite occur in grains large enough to be readily recognized. There are two types of quartz grains, one which is identified by its characteristic "blick" on rotation under crossed nicols, and the second which exhibits wavy extinction. The wavy extinction may be due to the successive extinction of a compound grain as suggested by Grawe.[6] It was first thought that these grains were orthoclase, but an examination of spectrograms of both the light and dark colored portions of the rock taken with a quartz spectrograph showed that there was no potassium present. Chlorite flakes are found oriented in parallel position and this arrangement is constant across both the light and dark bands. The only essential difference in mineral composition between the two portions of the rock is the presence of hematite in the darker areas. The hematite is very finely disseminated through the darker parts and appears to grade gradually into the lighter portions. What appears to be limonite in reflected light is scattered through the lighter parts of the rock in a manner similar to that of hematite in the darker portions. The cavities mentioned in the macroscopic description are empty and show a slight concentration of hematite around them.

ORIGIN OF THE ROCK AND BANDING

The origin of the "Zebra" rock, aside from its peculiar banding which is secondary, has not been suggested. The microscopic examination of thin sections leads the author to believe that the rock was originally a very fine grained detrital sediment. The reason for this statement is the fact that in some of the fine grained Paleozoic sediments this association of detrital and secondary quartz, in a fine

[5] Color designations are those taken from color chart for *Field Description of Sedimentary Rocks*, National Research Council, Washington, D. C., 1928.

[6] Grawe, O. R., Study of Black Shale, *Econ. Geol.*, Vol. **XXV**, p. 331, 1930.

grained ground mass containing chlorite, is very common. As an example, some of the finer Upper Devonian shales of central New York may be cited. Blatchford has found volcanic tuffs and breccias interlaminated with the rocks of the region and it is very likely also that the "Zebra" rock may be a fine grained representative of such a volcanic series.

There appear to be four explanations which may account for the very peculiar and regular banding noticed in the rock. They are: (1) original sedimentary banding of materials varying in composition sufficiently to give red and white colored bands, followed by deformation before complete solidification; (2) original markings due to crystallization of a fine grained flow rock, such as the leopardite from North Carolina (see Fig. 3 for comparison); (3) the result of infiltration of iron-bearing solutions into a uniformly white rock; or (4) due to the leaching of the hematite from a uniformly colored red rock.

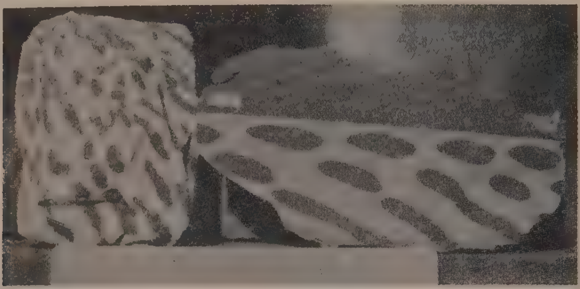

Fig. 3. Left, leopardite from North Carolina; right, typical "Zebra" rock.

Conclusion

The four explanations for the peculiar banding described in the "Zebra" rock are not especially convincing, but they appear to be the best that can be offered. The idea of an original sedimentary banding would seem to explain this banding and the divergence of bands, were they not so regular and clear cut. Mr. Hobson has pointed out that the heavy minerals are as plentiful in the light portion as in the dark. This phenomena might be explained as a result of crystallization from a magma but here again the regularity of the features seem to exclude this idea as well as the facts observed from a study of the thin sections. Mr. Hobson did not subscribe, in his abstract or complete paper, to the idea that the banding was the result of infiltration of hematite-bearing solutions into a uniformly white rock, but does leave the impression that a leaching or reduction of iron in a uniformly-colored red rock was not an adequate explanation.

Of all the theories advanced, the latter seems the most reasonable although the exact details and chemistry of the process are not clear. Evidence to support this theory was found in the thin sections and the hand specimens, namely, in the presence of the yellow mineral (limonite) scattered through the light colored portion in a manner similar to the hematite in the darker bands; and also in the leached zones or halos around the darker globules. There appears to be an analogy here between the halos noticed and those found in the red copper-bearing rocks of the Keweenawan peninsula. The main and apparently unexplainable objection to this theory and one for which the author can offer no explanation, is the manner in which the leaching solutions were so regularly and nicely controlled.

NOTES AND NEWS

WASHING SEDIMENTS TO OBTAIN MOST DESIRABLE SIZE OF GRAINS FOR MICROSCOPIC STUDY

Marcellus H. Stow, *Cornell University.*

A few years ago, when beginning sedimentary studies, the writer wondered what was the smallest size grain that could be conveniently identified in ordinary petrographic work on detrital materials. Several references were consulted and a few observations made on the minimum size of grains that could be readily examined. This was found to be 0.04 mm.

In order to determine the most satisfactory method of washing detrital sediments, several experiments were run on a sample of Moscow shale (Devonian). It was crushed to pass a 100 mesh sieve and treated with 1:1 hydrochloric acid until effervescence ceased. Water was added to form a column 10 cm. in depth. After agitating thoroughly, it was allowed to stand for a period of time, after which the size of the particles remaining in suspension was measured with the microscope.

After a settling period of twenty minutes the water was siphoned off to within one or two centimeters of the sediment in the beaker. All grains in suspension at the end of this time were clearly too fine grained for ordinary investigation.

The whole process was repeated with a settling period of ten minutes. Then the average grain was found to have a diameter of 0.008 mm. Washing was continued with ten minute intervals until the water was clear. Further washing was tried after settling periods of five minutes, three minutes, one minute and thirty seconds. The grain sizes at the end of these periods were found to be 0.02 mm., 0.03 mm., 0.04 mm., and 0.20 mm., respectively. Since grains smaller than 0.04 are quite difficult to identify readily, it was concluded that material remaining in suspension in a 10 cm. column of water for periods greater than one minute could be discarded without loss of desirable grains.

Those in charge of the journal wish to suggest that every effort be made by contributors possessing unfinished articles to complete the manuscripts and send them to the Editor before leaving for summer work. By so doing it is hoped that sufficient material might be accumulated to insure undelayed issues through the summer months.

Also, those who presented papers at the last annual meeting and indicated their intention to publish them in the American Mineralogist should notify the Editor when these articles will be available. Such action will be of great assistance in planning well balanced numbers for future issues.

The first commercial shaft ever sunk in the United States for potash has now reached a depth of a thousand feet, and potash minerals are ready to ship. The shaft has been sunk in New Mexico in a district recently explored by the U. S. Geological Survey. The shaft has passed through several workable beds of potash minerals, the best of which consists of sylvite.

A book of 325 pages with 127 plates and map, by James G. Manchester on "The Minerals of New York City and its Environs" has recently made its appearance. A review of this interesting work appears in another section of this journal. The book was published as a bulletin of the New York Mineralogical Club and can be purchased for $2.50 (plus 20¢ postage) by addressing the New York Mineralogical Club, care of the American Museum of Natural History, Central Park West and 77th St., New York City.

BOOKS REVIEWS

THE MINERALS OF NEW YORK CITY AND ITS ENVIRONS. James G. Manchester. Bull. New York Mineralogical Club: 3 (1) **1931**, (186 pages, 127 photographic illustrations, map). $2.50, plus 20 cents postage.

One Saturday, late in November, about twenty years ago, a New Yorker hurrying home from his daily work, hesitated on his way to the subway to examine an excavation for an apartment house at Broadway and 161st Street. The workmen had left and he descended into the cut. He found what looked like three faces of a feldspar crystal protruding from the rock. Not having any tools, he marked the spot, intending to extract the specimen later. During the night a storm arose, covering the ground with three inches of snow. Early on Sunday morning passing pedestrians stopped to see the strange sight of a man climbing over the rocks, and sweeping off the snow with a small whisk-broom. Two weeks of illness resulted from exposure, but the collector obtained a wonderful oligoclase crystal.[1]

Of such enthusiasm was this book written. Mr. Manchester has been one of the most active members of the New York Mineralogical Club, and for many years was its president. In a life crowded with the duties of an executive in an insurance company, he has nevertheless found time to indulge in the hobby of collecting minerals in the excavations and mines about New York, and to gather the data set forth in this volume.

This work treats of the minerals to be found within fifty miles of Columbus Circle in New York City: an area which includes many famous localities such as Franklin Furnace, Sterling Hill, Paterson and Bergen Hill, in New Jersey; Orange County, Bedford, Peekskill and Tilly Foster, in New York; and Branchville, Danbury and Trumbull in Connecticut.

The Introduction describes the geology of the area, with an account of the various mining and quarrying enterprises which have made the district so fruitful to collectors. Exactly 400 localities are then listed alphabetically with the minerals reported from each. This is followed by a list, also alphabetically arranged, of mineral species, varieties, synonyms and alterations recorded from the area. The 396 mineral species and important varieties have been tabulated in the order of Dana's System, with the chemical composition, form, color, hardness and specific gravity of each. Some 848 books and papers are listed in the Bibliography. The illustrations include 88 photographs of extraordinary specimens, 29 of mineral localities, and 10 showing the New York Mineralogical Club in the field. The mineral index is a model of completeness, as it not only lists all species, varieties, synonyms and alterations found in the district, but references are also given in each case to the Bibliography, Classified List, Locality List, and to the Illustrations.

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[1] Now in the American Museum of Natural History, and illustrated on Plate 39.

Collectors and curators should find this book a faithful guide, and it should go far toward stimulating a local interest in mineral collecting in the excavations of Manhattan.

Samuel G. Gordon

DETERMINATION OF THE OPAQUE MINERALS. C. Mason Farnham. McGraw-Hill Book Company, Inc., New York, 1931. 236 pages. $3.50.

The identification and association of minerals serve as the basis on which mining geologists and engineers build working hypotheses regarding the persistency of ore at depth and the recognition of mineral zones. In the past insufficient attention has been given the study relating to opaque mineral identification as only two textbooks on this subject have appeared in English in the past fifteen years. The new book by Farnham therefore does not greet an overcrowded field.

Many reviews ignore the author's statement of the purpose of his book and proceed to measure its applicability to their chosen fields. Farnham has restricted his choice of methods, "so as to be available with apparatus consisting only of a suitable microscope, a few bottles containing reagents, hand-grinding machines, and a few abrasives." Other methods may be extremely valuable but, as the author states, are "not practical for the field geologist or the investigator who is located in an isolated mining district."

While the science of mineralogy at present generally recognizes about 261 opaque minerals, 94 have been shown by the microscope to be mixtures of minerals or belong to doubtful species. (It is the opinion of the reviewer that benjaminite should also have been added to the list of mixtures).

Although the scope of the book is primarily limited to the identification of the opaque minerals, 51 somewhat transparent minerals have been added as they occur associated with the opaque minerals in ore deposits. In the tables sixty-five divisions are recognized based on the effects produced by six standard reagents- HNO_3, KCN, HCl, $FeCl_3$, KOH, and $HgCl_2$. Numerous supplementary tables are also included on "Minerals with a Distinctive Color," "Minerals with a Colored Powder," "Minerals Arranged According to Hardness, Specific Gravity, Electrical Conductivity, etc." Fourteen pages are devoted to a description of the technique employed in preparing the polished section while a rather extensive bibliography should prove extremely helpful to the serious-minded student.

The book is up to date including a brief discussion of the behavior of polarized light upon opaque minerals, and should make a strong appeal to both the student in the laboratory and the practical man in the field who, by necessity, is restricted in the number of his reagents and the amount of his equipment.

Ernest E. Fairbanks

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB

The regular meeting of the New York Mineralogical Club was held at the American Museum of Natural History, on the evening of February 18, 1931, with President Allen in the chair. Mr. Harry W. Hicks of Jersey City was proposed for membership, the name being referred to the membership committee.

A nominating committee was elected to bring in a list of candidates for officers of the Club for the ensuing year. An advance copy of the new Club publication, "The Minerals of New York City and Its Environs," was on hand for inspection. The book was enthusiastically praised by those present. It is a work of 168 pages with many exceptionally fine plates, and covers the field exhaustively, giving a full bibliography of the subject in all its aspects. It was announced that the book would be ready for delivery in about a fortnight, and that the price would be $2 to members of the Club and $2.50 to others. A check was voted drawn to meet the Club's share of the cost of publication.

The speaker of the evening was Professor Paul F. Kerr of Columbia University. His paper discussed *The Geology of the Ventura Quadrangle*. Professor Kerr gave a most interesting and careful account of that important California area lying somewhat northwest of Los Angeles, illustrating his talk by means of lantern slides. He stated that the San Andreas fault is the key structure to the Coast ranges of California, and gave a detailed and vivid description of the special characteristics of the different units of the quadrangle.

At the invitation of the president, various members, including Messrs. Carlson, Hoadley, Broadwell and the secretary showed specimens of recent acquisition, or described new mineralogical "finds." President Allen spoke of some interesting features of the shore sands of New York and New Jersey.

JAMES F. MORTON, *Secretary*

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, February 5, 1931

A stated meeting of the Philadelphia Mineralogical Society was held on the above date, Mr. Toothaker presiding. Fifty-five persons including forty-five members, were present.

Dr. Edgar T. Wherry, of the University of Pennsylvania, spoke on *The Chemistry of Some Common Silicates*. Dr. Wherry reviewed the classification of silicates as proposed by Dana and Clarke, and stated Tschermak's idea of silicate composition as derived from the dehydration of silicate gels. The structure of many minerals cannot be explained by the ordinary valence theory, and the speaker stressed his belief that the first great advance in explaining the chemical structure of minerals was the coördination theory of Werner. The work of V. M. Goldschmidt was also a great step forward when he cleared up many of the problems relating to isomorphism and polymorphism by his concept of the deformability of atoms and groups. Intimately connected with V. M. Goldschmidt's work is the application of the theory of point groups and space lattices in X-ray study. The troublesome phenomena of unfilled lattices was described and illustrated by the mineral mullite. The orthosilicates were referred to making use of olivine, where the characteristic group is (SiO_4). Beryl with a characteristic group (Si_2O_7) is a parasilicate. The pyroxenes and amphiboles are common metasilicates and are characterized by a (SiO_3) group. Long chains of these groups give these minerals a fibrous structure.

A vote of thanks was given Dr. Wherry for his highly instructive talk.

Lester W. Strock, *Secretary*

NEWARK MINERALOGICAL SOCIETY

The 116th meeting was held in the Library of the Newark Technical school on December 7, 1930. The program for the afternoon comprised an illustrated lecture by Mr. J. Claudius Boyle of the Mineralogical Department, Children's Museum, Brooklyn, New York, on *Through Part of Ontario and Quebec with Hammer and Chisel*, illustrated with specimens and slides.

The 117th regular meeting was held on January 4, 1931. The program consisted of a short paper by Mr. Herbert L. Thowless on *Dew, Frost, Ice and Snow Crystals*, illustrated with slides, photographs, etc. Some of the members brought pictures, books and specimens to illustrate the Hexagonal System.

The 118th meeting was held on February 1, 1931. The program consisted of a *Symposium on Limonite*. The discussion being led by Dr. C. M. Edward Schroeder. Specimens of limonite, hematite and allied minerals were exhibited.

The 119th meeting was held on March 1, 1931. The program consisted of a *Symposium on Copper*, the discussion being led by Mr. Paul Walther. Specimens of copper and allied minerals were exhibited.

The meetings were fairly well attended by members and guests.

Herbert L. Thowless, *Secretary*

NEW MINERAL NAMES

Allodelphite

P. Quensel and H. von Eckermann: Allodelphite, a new silico-arsenate from Långban. *Geol. Fören. Förh. Stockholm*, **52**, 639–646, 1930.

Name: From the greek meaning brother, alluding to the difference as well as the relationship to synadelphite.

Chemical Properties: A silico-arsenite of manganese and minor bases: $5RO\cdot 2R_2O_3\cdot As_2O_3\cdot SiO_2\cdot 5H_2O$; R = Mn chiefly, with Al, Ca and Mg. Analysis (by G. Karl Almstron): SiO_2 6.23, As_2O_3 19.48, Sb_2O_3 0.14, Al_2O_3 1.50, Fe_2O_3, 0.98, Mn_2O_3 30.19, MnO 23.17, PbO 0.39, CaO 1.10, MgO 6.22, H_2O 0.74, Na_2O 0.53, H_2O 8.82. Sum 99.49.

Crystallographical Properties: Probably orthorhombic. Habit elongated tabular crystals, the elongated faces etched and vertically striated. Forms: $a(100)$, $o(102)$, $i(120)$, $f(111)$, $n(126)$. $a:b:c=0.9402:1:1.1067$.

Physical and Optical Properties: Color dark reddish brown, deep wine red by transmitted light. Streak chocolate brown. Luster sub-metallic. Fracture conchoidal. Sp. Gr. 3.573.

Uniaxial or biaxial with $2V=2°-3°$. Positive. Not pleochroic. $\alpha=1.7493$, $\gamma=1.7244$. Extinction sometimes inclined to the elongation $2°-3°$.

Occurrence: Found with manganophyllite and hausmannite along joints in dolomite, either as groups of radially arranged elongated crystals similar to allactite or as thin crusts of small well defined elongated tabular crystals in open cavities.

Discussion: In crystallographical, chemical and X-ray properties the mineral is very similar to synadelphite.

W. F. Foshag